STRUCTURAL PERFORMANCE OF PRECAST SELF-COMPACTING CONCRETE BEAM CONSISITING BANANA SKIN POWDER AND COIR FIBRE UNDER FLEXURAL LOAD

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DEDICATION

I would like to dedicate my thesis work to my parents Abdul Qayoom Lakhiar and Haleema Khatoon, my grandfather Late Haji Akhound Abdul Rasool Lakhiar and maternal grandfather Akhound Abdul Rauf Lakhiar for their endless love, prayers and support in all endeavours of life. Without them, none of my success would be possible.

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ABSTRACT

In present, environmental pollution is become serious problem. Agricultural products generate waste in huge amount, which creates the disposal and environmental problems such as leachate and odour smell. An initiative is needed to reduce these wastes and utilize the agricultural waste as a construction material like concrete. The agricultural waste widely used as supplementary cementing material, filler and fibre reinforcement. In this research Banana Skin Powder (BSP) and Coir Fibre (CF) utilized as partially cementing material and filler respectively, to reduce the agricultural waste and save the natural recourses which is used in manufacturing of cement and reduces the emission of carbon dioxide (CO_2) in atmosphere. This research investigated the physical and chemical properties of BSP. The fresh properties (filling ability, passing ability and segregation resistance) and hardened properties such as compressive, tensile, flexural strength, modulus of elasticity and Poisson's ratio of self-compacting concrete (SCC) consisting BSP and CF were studied experimentally. The ultimate load, crack pattern and load deflection profile of Precast Self-Compacting Concrete containing BSP and CF Beam (PSCC-BSP-CF-B) were analysed under flexural load by experimental work. The results were validated by Finite Element Analysis (FEA) using software package Abaqus. The outcomes from XRF test proved that the BSP is the Class F pozzolan which contributes to enhance the strength of SCC. The fresh properties of SCC like filling ability, passing ability and segregation resistance were satisfied the EFNARC SCC specifications. The mechanical properties and ultimate bearing capacity were improved with the BSP and CF incorporation in SCC. The crack pattern predicts the PSCC-B were fail in flexural. The deflection became lower when CF and BSP were added in PSCC-B. The optimum percentage which was found through experimental tests are 0.4%BSP and 0.5% for CF. The crack pattern, ultimate load and deflection in PSCC-B using FEA through ABAQUS have 2% to 8% difference compare to experimental studies.

ABSTRAK

Pada masa ini, pencemaran alam sekitar menjadi masalah yang serius sejak sedekad yang lalu. Produk pertanian menghasilkan sisa buangan dalam jumlah yang banyak, yang menyebabkan masalah untuk pelupusan dan masalah kepada alam sekitar seperti 'leachate' dan bau. Inisiatif diperlukan untuk mengurangkan sisa-sisa ini dan digunakan sebagai bahan dalam binaan seperti konkrit. Sisa pertanian digunakan secara meluas sebagai bahan tambahan dalam simen, pengisi dan serat penguat. Dalam kajian ini, serbuk kulit pisang (BSP) dan sabut kelapa (CF) digunakan sebagai bahan pengisi dan separa pengisi untuk mengurangkan sisa pertanian dan menyelamatkan alam semula jadi yang digunakan dalam pembuatan simen dan mengurangkan pelepasan karbon di oksida (CO2) di atmosfera. Kajian ini mengkaji ciri-ciri fizikal dan kimia BSP dan CF, sifat-sifat konkrit segar (keupayaan mengisi, keupayaan lulus dan rintangan pemisahan) dan sifat-sifat konkrit keras seperti kekuatan mampatan, tegangan, lenturan, keanjalan modulus dan nisbah Poisson's untuk konkrit padat sendiri (SCC) yang mengandungi BSP dan CF. Beban 'ultimate', corak retak dan profil pesongan beban 'Precast Concrete Self-Compacting' yang mengandungi BSP dan rasuk CF (PSCC-BSP-CF-B) yang dianalisis pada beban lenturan secara eksperimen dan disahkan oleh 'Finite Element Analysis' (FEA) menggunakan perisian Abaqus. Hasilnya menunjukkan bahawa BSP adalah pozzolan Kelas F yang menyumbang untuk meningkatkan kekuatan pada SCC. Ciri-ciri segar SCC seperti keupayaan mengisi, keupayaan lulus dan rintangan pemisahan telah memenuhi spesifikasi EFNARC SCC. Sifat-sifat mekanikal dan 'ultimate' bertambah baik dengan penambahan BSP dan CF di dalam SCC. Corak retak meramalkan PSCC-B gagal dalam lenturan. Pesongan menjadi lebih rendah apabila CF dan BSP ditambah dalam PSCC-B. Peratusan optimum yang didapati melalui uji kaji ialah 0.4% BSP dan 0.5% daripada CF. Walaubagaimanapun diperiksa corak retak, beban muktamad dan pesongan di PSCC-B menggunakan FEA melalui ABAQUS, mendapati ia mempunyai perbezaan 2% hingga 8% berbanding dengan hasil kajian eksperimen.

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LIST OF ABBREVIATIONS

Al_2O_3	-	Aluminum trioxide
ASTM	-	American Standard Test Method
BCA	-	British Cement Association
BS	-	British Standard
BSP	-	Banana Skin Powder
CF	-	Coir Fibre
CaO	-	Calcium oxide (lime)
$Ca(OH)_2$	-	Calcium hydroxide
CO_2	-	Carbon dioxide
C-S-H	-	Calcium silicate hydrate
ESA	-	Eggshells ash
Fe_2O_3	-	Ferric oxide (iron)
FKAAS	-	Faculty of Civil and Environmental Engineering
GFC	-	Green foamed concrete
K_2O	-	Potassium oxide
LOI	-	Loss of Ignition
MgO	-	Magnesium oxide
MPa	-	Mega Pascal
Na_2O	-	Sodium oxide
OPC	-	Ordinary Portland cement
POFA	-	Palm oil fuel ash
PSD	-	Particle size distribution
PSCC	-	Precast self-compacting concrete
SCC	-	Self-compacting concrete
SCM	-	Supplementary cementitious materials
SEM	-	Scanning electron microscope

S_g	-	Specific gravity
SSA	-	Specific surface area
SiO_2	-	Silicon dioxide (silica)
SO_3	-	Sulfur trioxide (sulfuric anhydride)
UHI	-	Urban heat intensity
UTHM	-	Universiti Tun Hussein Onn Malaysia
w/a	-	Water absorption
w/b	-	Water – Binder
w/c	-	Water – Cement
XRF	-	X-Ray fluorescence

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete, a combination of binder, aggregates, and water (Jin & Chen, 2013), has developed as the main material in the construction industry due to its high durability, feasibility and flexibility. Its utilization as building material is increasing day by day. However, concrete has its shortcomings which include low strength, low workability and low segregation resistance. By improving its strength, workability and segregation resistance, concrete will become more durable and easily constructed, with easiness in the placing, handling and pouring process. One of the alternative methods to develop high strength and high-performance concrete is by utilizing certain admixtures and reduce the coarse aggregate content (EFNARC, 2005).

Self-compacting concrete (SCC) is an innovative concrete, produced by utilizing superplasticizer to make the concrete flowable in such a way that it can flow by its own weight and fill the entire framework without any external effort. SCC is studied in this project due to its several advantages which include faster construction, reduction in manpower, easier placing, uniform and complete consolidation, better surface finishes, improved durability, increased strength, non-segregated and safer working environment (Uysal, 2018 and Okamura & Ouchi, 2003). Its high workability and strength are highly desired for structure element.

Meanwhile, solid wastes from plantation have been produced in a large scale. The disposal and the proper management of this waste is the critical problem in Malaysia. This issue generates a lot of environmental problems such as disposal,

biodegradation, gas and leachate generation (Liew *et al.*, 2015). The best solution to deal with this problem is to utilize these wastes as construction material.

Agricultural wastes are wastes generated from plantation such as banana leaves, sago waste, kenaf, coir, pineapple skin and pineapple leaves, rice husk and palm oil fuel ash. These wastes can be utilized as concrete materials either as sand and cement replacement, additives or filler. Kannan (2018) and Le *et al.,* (2018) have used agricultural waste as supplementary cementing material such as POFA and rice husk ash. Whereas, Bala *et al.,* (2018) and Chin *et al.,* (2018) used the plant fibres which includes coir, sisal, jute, ramie bast, pineapple leaf, kenaf bast, abaca leaf, date, bamboo, palm, banana, hemp, flax, cotton and sugarcane as an alternative sources of steel and artificial fibres to be used in composites such as cement paste, mortar and concrete to increase its strength properties.

Banana plantation is the second most cultivated plantation in Malaysia which occupies the area about 26,000 hectares and gives the production up to 530,000 metric ton per year (Mekhilef *et al.,* 2011). Hence, the banana skin wastes are generated in ample amount with respect to other fruit waste. Banana skin creates leachate when it is disposed into the landfill and created environmental pollution (Ahmad & Danish, 2018). Deelaman *et al.,* (2018) and Anowai & Job (2017) each used banana skin waste as an alternative source of steel and artificial fibres, and banana leaves as cement replacement to improve the strength, physical and chemical properties of concrete, respectively.

This study developed the self-compacting concrete, SCC, incorporating banana skin powder (BSP) as partial cement replacement. BSP is categorized as pozzolanic material which has tendency to react with calcium hydroxide in the presence of water and produced the calcium silicate hydrate gel (C-S-H). This gel plays important role in binding all the particles together in the SCC concrete mixture.

Concrete possesses high compressive strength but weak in tensile and flexural strength; therefore, reinforcement in concrete is necessary. Various fibres have been used to improve the tensile and flexural strength of concrete (Vishwakarma & Ramachandran, 2018). Natural fibre such as coir fibre possesses physical and chemical characteristics which can be utilized in the development of reinforced concrete material. The coir fibres are easily available in huge amount. Therefore, coir fibre (CF) was used as filler in this study to control the shrinkage and surface cracking of SCC concrete.

This research studied the potential of BSP and CF, each as cement replacement and filler, respectively, in SCC-BSP-CF mixture, by investigating its fresh and hardened properties, and its structural performance subjected to flexure load. The physical and chemical properties of BSP was determined to determine its suitability as a binding agent in concrete. The fresh and hardened state properties of SCC containing BSP and CF was investigated and optimum percentage of BSP and CF was determined. The structural performance of PSCC-BSP-CF beam was studied under four point bending load test. The parametric study was further conducted using finite element method using ABAQUS software. The results obtained were studied and analyse to determine both material and geometrical properties' influences on the structural behaviour of the beam.

1.2 Problem statement

In construction industry, conventional concrete is mostly utilized even though it has demerits which includes less workability and more labourers needed during its fabrication and installation. Self-compacting concrete (SCC) has the capability to flow by its own weight, and able to spread into a formwork with less segregation. SCC is superior to conventional concrete in terms of placing of concrete especially in the congested reinforcement. SCC requires no compaction. Thus, contributes to energy saving and reduced man power (Murdono *et al.*, 2017).

Cement, as binder, is essential in all types of concrete mixtures. During the fabrication of concrete, carbon dioxide (CO_2) is emitted into the atmosphere and creates global warming. According to Turner & Collins (2013), 5%-8% CO_2 is emitted during the production of concrete. Meanwhile, in Malaysia, more than 30,000 tons of agricultural solid waste (ASW) is generated in one day. The generation of ASW increased 3% annually which caused great impact on environment (Johari *et al.*, 2014). Banana, as one of the most harvested product in Malaysia (Deepak *et al.*, 2014), generated almost 35% of banana production which creates the environmental pollution and disposal problem (Guerrero *et al.*, (2018) and Sagar *et al.*, (2018)).

Therefore, to reduce man power and carbon dioxide emission, a study was undertaken to investigate the structural performance of beam fabricated from SCC incorporating BSP as cement replacement. Concrete beam under flexure, due to its

brittle property, is expected to experience crack propagation either at its mid-span or its support areas, or both. To control the crack propagation, CF was added as filler into the SCC-BSP mixture. CF has been found to have ability in boosting the tensile and flexural strength, control crack propagation and shrinkage of concrete (Adhavanathan & Neelaveni, 2017).

Finite element analysis (FEA) using Abaqus to model and simulate the precast SCC beams subjected to flexural load, was adopted. Validation of PSCC model was conducted by comparing the FEM results with the experimental results. Parametric study was conducted using various shear span length over depth ratio and utilizing the different material properties to obtain the structural performance of PSCC-BSC-CF beam under flexural load.

1.3 Research aim and objectives

The aim of this research is to investigate the structural performance of precast SCC beam incorporating banana skin powder and coir fibre, PSCC-BSP-CF, as cement replacement and filler, respectively, under flexural load.

The objectives of this work are:

i. To determine the physical and chemical properties of BSP and CF.
ii. To determine the fresh state and mechanical properties of SCC containing BSP and CF.
iii. To determine the ultimate load, load-deflection profiles, crack pattern and strain distribution of PSCC-BSP-CF beam under flexural load by means of experimental work.
iv. To analyse the influence of various parameters on ultimate load, crack pattern and load-deflection profiles of PSCC-BSP-CF beam subjected to flexural load by means of finite element method (FEM).

1.4 Scope and limitation of study

This research was conducted using both experiment and finite element analysis. The experimental work includes several laboratory works which was conducted to determine the chemical and physical properties of BSP and CF, and mechanical

properties and of PSCC beam incorporating BSP and CF. The four-point bending test was conducted to determine the structural behaviour of PSCC-BSP-CF beam subjected to flexural load. Finite element method, FEM, was used to conduct a parametric study on structural behaviour of PSCC-BSP-CF beam. The parameters study included various shear span length over depth ratio (a_v/d), various main reinforcement area and various length of PSCC-BSP-CF beam. Results from the flexural test were used to validate the PSCC-BSP-CF beam model and simulations.

The chemical and physical properties tests were conducted determine the particle size distribution of BSP and CF, microstructure morphology of BSP, chemical composition of BSP and water absorption of CF. Slump flow test, J-ring test and segregation resistance were performed to investigate the fresh properties of SCC. The hardened or mechanical properties which include compressive strength, tensile strength, modulus of elasticity (MOE) and Poisson's ratio were determined from compressive strength test on cubes, split tensile strength on cylinders and compressive strength of cylinders, respectively. The cubes with size 100mm x 100mm x 100mm were tested for compressive strength with various percentage of BSP; which are 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1%, as cement replacement at 7, 14, 28 days of age. The cylinders having 100 mm diameter and 200 mm length were tested to determine its tensile strength, MOE, and Poisson's ratio of SCC at 28 days. The optimum percentage of BSP that could be added to the SCC mixture was determined.

The CF with various percentage 0.5% and 1 % were incorporated in SCC-BSP mixture with optimum percentage of BSP to analyse the compressive strength, tensile strength, MOE, and Poisson's ratio of PSCC-BSP-CF mixture. Beams with dimensions 150mm x 300mm x 1500mm were cast and tested under four point load to examine the flexural performance of beam incorporating the optimum BSP and various percentage of CF at 28 days.

The parametric study was conducted on PSCC-BSP-CF beams to examine the ultimate load, cracking pattern and load deflection profiles by means of FEA. Beams were modelled using FEM, strengthened with main reinforcement and stirrups as suggested in the design of beam under flexure, by utilizing ABAQUS software. The results obtained from FEA were validated with the results obtained from experiment and further analysed using results from previous research and theory.

1.5 Significant of study

This study was conducted to determine the optimum percentage of BSP and CF, used as cement replacement and filler, respectively, in the SCC mixture. Utilization of BSP and CF in SCC is expected to improve the mechanical properties of SCC-SSP-CF mixture and structural behaviour of PSCC-BSP-CF beam under flexural load.

1.6 Thesis layout

This thesis consists of six (6) chapters. The content of each chapter is defined below:

Chapter 1 presents an introduction to this study which include the definition of SCC concrete and its advantages. It also discussed briefly the abundance of agriculture wastes which has been an important issue in Malaysia. Utilizing BSP and CF, each as cement replacement and filler, in SCC concrete is an alternative to reduce the CO_2 emission from the reaction of cement in concrete fabrication, and to reduce crack propagation due to flexure load, respectively. This chapter also discusses the problem statement, aim and objectives, scope, and significance of the study.

Chapter 2 presents the potential application of BSP and CF as new alternative construction materials. The related literature review on SCC and its advantages over the conventional concrete and utilization of partially cement replacing material from agricultural waste are also discussed. The structural behaviour of beam under flexural load are discussed from the review of previous research work. FEM modelling and simulations using ABAQUS are also explained in this chapter.

Chapter 3 presents the methodology of this research which includes experimental studies and FEA. The experimental studies include physical and chemical properties tests on BSP and CF, fresh and hardened state properties test on SCC-BSP-CF mixture, and structural behaviour of PSCC-BSP-CF beam under flexural load. The results obtained from the experiment are used to validate the PSCC-BSP-CF beam model using ABAQUS. Parametric study using FEA are conducted to study the effects of a_v/d ratio, area of main reinforcement, and beam's length on structural behaviour of PSCC-BSP-CF beam under flexure load.

Chapter 4 discusses and analyse the results obtained from the experimental work. The results include physical and chemical properties of BSP and CF, fresh state

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